Classification of Pectus Excavatum According to Objective Parameters From Chest Computed Tomography

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Background. **Previous classification systems of pectus excavatum have been based on subjective morphologic characteristics. We sought to suggest a new classification system derived from objective variables.**

Methods. **Patients who underwent surgical repair of pectus excavatum without a history of previous chest operations were included. Objective morphologic variables were measured from chest computed tomography scan images, and classification was performed by hierarchical clustering of measured indexes. Clinical relevance of the suggested classification was also verified.**

Results. **Included were 230 patients who underwent operation for pectus excavatum from January 2001 to August 2013. These patients were classified into two major groups: typical (group I; 197 [85.7%]) and atypical (group II; 33 [14.3%]). Group I was further classified into three subgroups according to flatness and symmetry of the chest wall. Group II was further classified into four subgroups according to the severity of sternal torsion and sternal angulation. Two unique types of deformity were identified in group II: the double distortion subgroup (group IIa; 8 [3.5%]) and the reverse torsion subgroup (group IIc; 16 [7.0%]). Scoliosis was more frequently associated with group IIa ($p = 0.008$).**

Conclusions. **Morphologic classification obtained from computed tomography indexes hierarchical clustering identified seven distinct subtypes of pectus excavatum.**

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Pectus excavatum is the most common chest wall anomaly and is characterized by a depression of the anterior chest wall. Most patients are asymptomatic, although some may present with cardiopulmonary symptoms [1]. Even in the absence of physical symptoms, many patients develop psychological problems due to a distorted body image and require medical consultation [2, 3]. The Ravitch procedure and the Nuss procedure [4] are the two most commonly performed operative techniques for the correction of pectus excavatum.

Many studies of pectus excavatum have focused on the optimal correction procedure [5], optimal age for repair [6–8], or the effect of correction on cardiopulmonary function [1, 9], while less attention has been devoted to classification systems. Furthermore, previous studies of the classification of pectus excavatum [10–12] have been based on subjective morphologic findings, and no study based on an objective analysis of morphology has been reported.

This study aimed to characterize morphologic features of pectus excavatum and to suggest a new objective classification system based on morphologic similarities. We attempted to classify pectus excavatum by using statistical clustering of chest computed tomography (CT) indexes. We hypothesized that a newly developed classification would identify new types of pectus excavatum and that each subgroup might exhibit different clinical characteristics.

Patients and Methods

This study was approved by the Seoul National University Hospital Institutional Review Board (IRB Assurance Number: H-1502-099-650), and the requirement for informed consent was waived. A retrospective review of medical records and preoperative chest CT scans was performed for patients with pectus excavatum who underwent surgical repair. The exclusion criteria were (1) corrective operation after a previous sternotomy for a cardiac operation, (2) reoperation for recurrent pectus excavatum after a corrective procedure, (3) an operation without preoperative chest CT, and (4) mixed-type deformity with combined pectus excavatum and carinatum.

Five representative variables—the pectus index (PI), the asymmetry index (AI), the flatness index (FI), the sternal torsion angle (STA), and the angle of Louis (AoL)—were measured from chest CT scans image slices and chest

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Abbreviations and Acronyms

AI = asymmetry index
AoL = angle of Louis
AP = anteroposterior
CI = confidence interval
CT = computed tomography
CTD = connective tissue disease
FI = flatness index
OR = odds ratio
PI = pectus index
STA = sternal torsion angle

roentgenograms. The definitions of the representative variables followed previous studies (Fig 1):

1. PI = (longest lateral distance of the chest wall)/(shortest anteroposterior distance between the most depressed point of the chest wall and vertebra) [13];
2. AI = (longest anteroposterior distance of the left chest wall)/(longest anteroposterior distance of the right chest wall) [14];
3. FI = (longest lateral distance of the chest wall)/(longer of the two longest anteroposterior distances of the left and right chest wall) [15];
4. STA = angle between the sternum and a horizontal line, with a positive value indicating counterclockwise rotation of the sternum and a negative value indicating clockwise rotation; and
5. AoL = angle between the manubrium and the body of the sternum in the sagittal plane.

Classification was performed by hierarchical clustering using these five variables as clustering variables with the method of average linkages between groups. The number of clusters was determined by assuming that no cluster would include fewer than 5 patients. Correlations among variables were evaluated using Pearson correlation analysis to obtain further descriptive explanation of the proposed classification system. Characteristics of each group were compared by the Kruskal-Wallis test for continuous variables and the Fisher exact test for categoric variables. For multivariate analysis, binary logistic regression or logistic regression with the Firth penalized likelihood bias-reduction method was adopted to verify the clinical implications. In addition, a multivariate logistic regression of representative variables was separately performed to supplement the association of individual parameters with clinical implications. Statistical analysis was performed using SPSS 18.0 (IBM Corp, Armonk, NY) and SAS 9.3 (SAS Institute, Inc, Cary, NC) software. Certified statisticians assisted us and reviewed the statistical analysis.

Results

Corrective operations for pectus excavatum were performed in 296 patients in Seoul National University Hospital from January 2001 to August 2013. After excluding patients with a history of sternotomy for a cardiac operation (n = 8) or an operation for recurrent pectus excavatum (n = 24), those with no preoperative CT scan (n = 32), and those with combined-type deformity (pectus excavatum and carinatum, n = 2), 230 patients were included in the final analysis.

The median age of the patients was 6.0 years (range, 2.1 to 30.1 years), and the patient group exhibited male predominance (190 [82.6%]). Patients were treated with the Nuss (197 [85.7%]) or Ravitch procedure (33 [14.3%]). The most common comorbidity was scoliosis (17 [7.4%]). Connective tissue diseases were identified in 7 patients (3.0%), including Marfan syndrome in 5 (2.2%), Loeys-Dietz in 1 (0.4%), and Ehlers-Danlos syndrome in 1 (0.4%). Other anomalies detected by chest CT were congenital cystic adenomatoid malformation in 3 patients

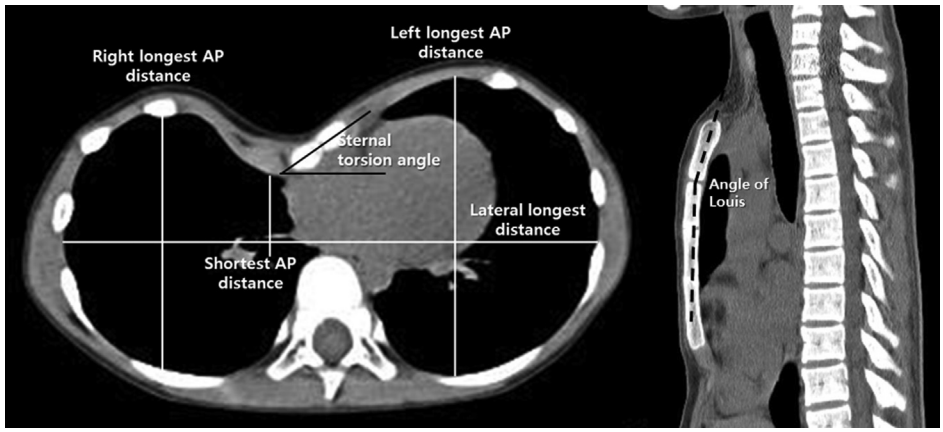

Fig 1. Definition of the variables: (Left panel) pectus index = (longest lateral distance of the chest wall)/(shortest anteroposterior [AP] distance between the most depressed point and vertebra); asymmetry index = (longest AP distance of the left chest wall)/(longest AP distance of the right chest wall); flatness index = (longest lateral distance of the chest wall)/(longer of the two longest AP distances of the left and right chest wall); sternal torsion angle = angle between the sternum and a horizontal line, with a positive value indicating counterclockwise rotation of the sternum; (Right panel) angle of Louis = angle between the manubrium and body of the sternum in the sagittal plane on computed tomography image or simple lateral chest roentgenogram.